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USE OF ERTS DATA FOR MAPPING ARCTIC SEA ICE

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16. Abstract

The purpose of this investigation is to evaluate the application of ERTS data for detecting and mapping Arctic sea ice. The specific objectives are to determine the spectral bands most suitable for detecting ice, to measure the scale and types of ice features that can be detected, and to develop interpretive techniques for differentiating ice from clouds and for mapping ice concentrations. The initial results of analyses for three Arctic areas indicate that sea ice is detectable in all of the ERTS MSS spectral bands and can be distinguished from cloud through a number of interpretive keys. Overall, the MSS-4 and MSS-5 bands appear to be better for mapping ice boundaries, whereas the MSS-7 band provides valuable information on ice type and ice surface features. Several ice types can be identified in the ERTS data, and ice features as small as the "small floe" (20 to 100 m across) can be detected. Ice concentrations mapped from the ERTS imagery are in good agreement with the limited amount of correlative data available to date.

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PREFACE

The purpose of this investigation is to evaluate the application of ERTS data for detecting and mapping Arctic sea ice. The specific objectives are to determine the spectral bands most suitable for detecting ice, to measure the scale and types of ice features that can be detected, and to develop interpretive techniques for differentiating ice from clouds and for mapping ice concentrations. The ERTS data are being analyzed mainly for three Arctic areas, the eastern Beaufort Sea, Baffin Bay, and the Greenland Sea.

The initial results indicate that sea ice is detectable in all of the ERTS MSS spectral bands because of its high reflectance, and can be distinguished from cloud through a number of interpretive keys. Overall, the MSS-4 (0.5 to 0.6 μm) and MSS-5 (0.6 to 0.7 μm) bands appear to be better for mapping ice boundaries, whereas the MSS-7 (0.8 to 1.1 μm) band provides valuable information on ice type and ice surface features. Ice types that appear to be identifiable in the ERTS data include ice floes, pack ice of various concentrations, ice belts, brash ice, rotten ice, fast ice, leads, fractures, cracks, puddles, and thaw holes.

Ice features as small as the "small floe" (20 to 100 m across) can be detected, and the sizes of features somewhat smaller than 100 m across can be measured from enlarged ERTS prints. Ice concentrations can be mapped, and the resulting concentrations are in good agreement with the limited amount of correlative data available to date. Some large floes can be recognized over intervals of as long as 20 days, enabling mean ice movements to be measured.

P. P. Blank

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1. INTRODUCTION

1.1 Purpose and Objectives

The purpose of this investigation is to evaluate the application of ERTS data for detecting and mapping Arctic sea ice. The specific objectives are to determine the spectral bands most suitable for detecting ice, to measure the scale and types of ice features that can be detected, and to develop interpretive techniques for differentiating ice from clouds and for mapping ice concentrations. Standard aerial survey ice charts are being used as the primary source of correlative data to determine the reliability with which ice boundaries and concentrations can be mapped in comparison with other sources of ice observations. The ERTS data are being analyzed mainly for three Arctic areas, the eastern Beaufort Sea, Baffin Bay, and the Greenland Sea.

Because of the inaccessibility of the polar regions, ice survey, which is required for both economic and scientific purposes, is by its very nature a problem that can benefit from space technology. The results of this study will lead eventually to the operational use of future satellite data and, thus, to a more cost-effective means for ice survey.

1.2 Summary of Work Performed During Reporting Period

During this reporting period additional ERTS data covering the specified Arctic geographical areas have been received, bringing the total data sample to nearly 150 passes. A large number of the passes received early in the contract period, however, were found to be unusable because of nearly 100% cloud cover. Therefore, early in this reporting period, through consultation with the technical monitor, the cloud restriction was reduced to 50%.

In the processing of the data, mosaics have been prepared for the passes containing more than one frame using the 9.5 inch paper prints. Also, enlargements have been made for selected areas in order to map in greater detail the small scale ice features. In the processing of the enlargements from the 70 mm negatives, various exposures and processing procedures were employed. From this experimentation is was found that the original processing of the 9.5 inch prints is not optimum for depicting sea ice. By exposing the negatives such that the land features of Greenland (mostly glaciers and snow-covered mountains) became saturated, many ice features not detectable in the original prints become visible.

The analyses during this period have been concentrated on mapping ice features in detail for selected areas from the original prints and the enlargements. Types of ice have been identified, ice concentrations mapped, and the scales of various features measured. The displacements of recognizable ice features and the movements of ice boundaries over 24-hour periods (when repetitive coverage is available) and over the longer periods between subsequent ERTS cycles have also been mapped. The analyses are described in more detail in later sections of the report.

Some correlative ice charts have been received from the Canadian Ice Forecasting Central. Additional data for the areas and periods corresponding to the ERTS analyses have been requested from the Ice Forecast Office of the Navy Fleet Weather Central at Suitland.

2. MAIN TEXT

2.1 ERTS Data Sample

ERTS-1 data have been received for a total of 148 passes crossing the specified Arctic areas. The initial screening of the data sample has revealed, however, that more than half of these passes are not usable for further analysis either because of cloud obscuration or because of the lack of visible ice. The 67 passes in which significant amounts of sea ice can be identified are within the areas listed in Table 1.

The data sample is from the period between late July and late October 1972. Because of the polar dark period in winter, ERTS data for the specified areas have not been collected since October. Also, as a result of the large number of the early passes received that were not usable because of nearly 100% cloud cover, the tolerable cloud amount has been reduced to 50% for all subsequent data to be received through the standing order procedure.

2.2 Correlative Ice Data

Aerial ice survey charts for late July 1972 for the Banks Island - Amundsen Gulf and northern Hudson Bay areas have been obtained from the Canadian Ice Forecasting Central. Similar aerial survey charts have been requested for additional areas and time periods from the Ice Forecast Office of the Navy Fleet Weather Central at Suitland. Standard meteorological charts are being used to determine general wind flow and temperature conditions.

TABLE 1

SUMMARY OF ERTS DATA SAMPLE USABLE

FOR MAPPING SEA ICE

Area	Number of Passes
Mid-Beaufort Sea south to Alaska Coast	20
Prince Patrick Island, Melville Island, Banks Island, and Amundsen Gulf	24
Axel Heiberg Island, Ellef Ringnes Island, and Amund Ringnes Island	2
Hudson Bay	3
Labrador Sea, Baffin, and Ellesmere Islands	4
Devon Island, Cornwallis Island, Somerset Island, and Prince of Wales Island	5
Baffin Bay (along West Coast of Greenland)	2
Greenland Sea (along East Coast of Greenland)	7

2.3 Data Processing

The ERTS data have been received in the form of 70 mm negative transparencies and 9.5 in positive paper prints. For passes containing more than one frame, mosaics have been prepared using the paper prints. For selected areas enlarged prints have also been made from the negatives. An attempt to make prints from some of the original negatives received from the NDPF was not successful because the negatives were of a too high density to permit their use with the standard equipment available at the ERT photographic laboratory. Negatives received subsequently have been of a better quality and have been found to be usable for making prints.

Various scales of enlargements have been made depending on the size of the area being enlarged. The maximum sized prints made are about twice the size of the 9.5 inch prints, such that the scale is about 1:500,000 as compared to the original 1:1 million scale. The exposure time has also been varied in the photo processing. From these experiments, it has been found that when longer exposure times are used such that the snow-covered land areas become completely saturated, many sea ice features not visible in the original print can be detected. Thus, the original processing does not appear optimum for sea ice depiction. The results of these experiments are discussed more thoroughly in Section 2.5.5.

2.4 Analysis Procedures

The initial review of the MSS data sample and very limited RBV sample indicated that sea ice can be identified in all of the spectral bands because of its high reflectance. Overall, the MSS-4 band (0.5 to 0.6 μm) appears to be the most useful for mapping ice boundaries because more ice features can be detected than in the other bands. In some instances, however, the ice covered areas are saturated in the MSS-4 band, resulting in a loss of ice detail and the obscuration of features on the ice surface. In these instances, the MSS-5 band (0.6 to 0.7 μm) was used in place of the MSS-4 data. Further analyses have shown that the MSS-7 data (0.8 to 1.1 μm) can provide valuable information on ice type and on ice surface characteristics. The results of the preliminary multispectral analyses are summarized in Section 2.6.

Although ice and clouds may have similar reflectances, ice can be distinguished from clouds through the following interpretive keys:

1. The brightness of ice fields and large ice floes is often more uniform than that of clouds. Clouds usually exhibit an uneven texture, such as is common with altocumulus or stratocumulus cloud. Also, ice floes and features such as leads and cracks within an ice field can at times be detected through thin cirriform cloud cover.

2. Cloud shadows can often be detected on the underlying ice surface.

3. Edges of most ice features, particularly ice floes, are more distinct than edges of clouds.

4. Ice cover fits coastlines and islands, permitting land features to be recognized.

5. The spatial frequencies of ice features are not characteristic of cloud patterns, at least the cloud patterns seen previously in meteorological satellite data and pictures from manned space flights. These features include ice floes surrounded by broken ice, narrow ice bands, and spiral patterns induced by ocean currents.

6. When repetitive coverage is available, some ice features remain stable over the 24-hour interval between observations. Even at the longer periods between ERTS cycles, some large floes can still be identified.

Following the identification of ice features, the geographic gridding of the ERTS frames is corrected if necessary. In most of the frames some correction was applied, the correction factor being generated by checking the locations of land features against standard maps. When no land reference is visible, such as in the data over the Beaufort Sea, the accuracy of the gridding cannot be checked. The maps found to be most useful for use in the analysis of the ERTS data are the Operational Navigation Charts (ONC Series). These maps are of a 1:1 million scale, essentially the same scale as that of the 9.5 inch prints.

Ice features, including the locations of ice boundaries, ice concentrations, and surface features, are being mapped from the mosaics and the enlarged prints using transparent acetate overlays. Identification of ice types and the scales of the ice features is made according to the terminology used in the WMO Sea Ice Nomenclature (WMO Pub. No. 259, TP.145). Ice movements are being mapped by transposing the positions of recognizable features onto the same overlay; large ice floes can often be identified even after intervals of nearly a month through recognition of shape and surface features.

2.5 Results of Analyses

2.5.1 Northern Hudson Bay

The initial analysis of two passes crossing Hudson Bay in the area south of Coats and Southampton Islands during late July has been completed (Pass 41, 26 July 1972, identifiers 1003-16273 through 1003-16282 (all bands));

Pass 55, 27 July 1972, identifiers 1004-16322 bands) and 1004-16324 (MSS only)). These data show a well-defined ice boundary southwest of Coats Island, with several bights and tongues apparently caused by a westerly surface wind flow. The ice along the immediate ice edge appears to consist mostly of brash or rotten ice, whereas the ice east of the edge consists of close or open pack ice. The majority of ice floes visible in these passes are vast, big, or medium sizes, although one giant ice floe is located near 61.7°N latitude and 85.6°W longitude. An ice belt is visible off the south coast of Southampton Island and some fast ice is apparent along the north coast of Coats Island. Four vast ice floes are also located just off the north coast of Coats Island. (NOTE: Ice floes are defined in the WMO sea-ice nomenclature as follows: Giant Floe - over 10 km across; Vast Floe - 2 to 10 km across; Big Floe - 500 to 2000 m across; Medium Floe - 100 to 500 m across; Small Floe - 20 to 100 m across.

The ice features mapped from the ERTS data are in good agreement with the conditions reported on the Canadian ice charts for the last week in July. These charts indicate: (a) A sharp, irregular (bights) ice edge extending southwest of Coats Island with ice-free water to the west; (b) an ice belt south of Southampton Island composed of 3/10's of first year ice of which 1/10 is medium or larger size floes; (c) an area of open water with less than 1 okta (1/8) ice concentration south of the ice belt and extending to the ice edge southwest of Coats Island; and (d) an area northwest of Coats Island in Fisher Strait comprised of 5/10's of first year ice of which 2/10's is medium or larger size floes with ridges and hummocks.

2.5.2 Banks Island - Amundsen Gulf

Initial analysis of four passes crossing the Banks Island, Amundsen Gulf, and Franklin Bay area during late July has also been completed (Pass 43, 26 July, identifiers 1003-19513 and 19511 (RBV); Pass 71, 28 July, identifiers 1005-20014 and 20012 (RBV); Pass 85, 29 July, identifiers 1006-20074 and 20071 (RBV); Pass 98, 30 July, identifiers 1007-20123 through 20132 (RBV)). Although much of Amundsen Gulf is open water in these passes, several isolated vast ice floes are located off the west coast of Banks Island, south of a giant ice floe (about 12 km x 50 km). A field of very close and close pack ice is located to the southeast of Banks Island and areas of close, open, and very open pack ice are located in Amundsen Gulf; these ice areas consist mostly of giant, vast, big and medium ice floes. Ice in Franklin Bay is composed of close, open and very open pack ice. Although one giant floe and several vast ice floes are observed in this region, the majority of the ice consists of big, medium and small, ice floes.

Aerial ice observation charts for the period 25-30 July indicate the following ice conditions in this region: (a) a giant ice floe off the southwest coast of Banks Island north of 72°N latitude composed entirely of first year ice with ridges 1 m high and some puddles; (b) a small area south of this giant ice floe indicated as 4/10's of first year ice of which 2/10's is comprised of medium or larger size floes; (c) the region of the Amundsen Gulf south of Banks Island to about 70.5°N is indicated as open water with some loose ice strips (total concentration of ice is indicated as less than 1 okta); and (d) several small areas of first year ice indicated south of 71°N into Franklin Bay with the majority of floes of the medium size category.

With the repetitive coverage of the Amundsen Gulf area, preliminary measurements of ice motion have also been made. Measurements of the motion of ice floes off the west coast of Banks Island during the 24-hour periods indicated a mean direction of motion toward the west-southwest at about 8 knots. The smaller floes nearer the coast appear to be moving more south-southwest at 8 to 11 knots, while in the area of 10 to 20 n.mi. offshore, larger floes moved toward the west to southwest at 5 to 8 knots. Little or no movement was observed in the giant floe to the north, although some deterioration (breaking off of smaller floes) did occur. Measurements of 24-hour motions of ice floes in western Franklin Bay in the area 10 to 20 miles off the coast of Cape Bathurst showed a mean direction toward the northwest at 7 to 15 knots into the Amundsen Gulf and Beaufort Sea. Two floes closer to the coast (7 miles offshore) moved southwest toward the coast of Cape Bathurst at about 6 knots.

2.5.3 Eastern Beaufort Sea

The analysis of two mosaiced ERTS passes crossing the eastern Beaufort Sea southwest of Prince Patrick Island has been completed. The passes are on 2 August (Pass 141, identifiers 1010-20284 through 1010-20302) and 22 August (Pass 420, identifiers 1030-20401 through 1030-20415). For the earlier pass, the MSS-5 and MSS-7 bands were used (the MSS-4 band was saturated); for the later pass, the MSS-4 and MSS-7 bands were used.

These data show a well-defined irregular ice boundary in the Beaufort Sea extending from near 74°N,125°W southwestward to approximately 72°N,138°W. On 2 August, a total of 13 very large "giant floes" (10 to 35 n.mi. across) can be identified within the area from about 72° to 75°N and 132° to 138°W (in the WMO sea ice nomenclature, a "giant floe" is defined as being greater than 6.3 n.mi. across). These floes are surrounded by ice concentrations consisting primarily of open pack (3 to 6 oktas) and close pack (6 to 7 oktas) with many various sized smaller floes. Twenty days later, on 22 August, the same 13 giant floes can be identified because of their shapes and surface features. Significant deterioration has occurred in only two of the floes; in these two floes, large areas (about 1/4 of the original floe size) have apparently broken off their southern edges and broken into smaller floes. In the 20-day period, however, the overall ice concentrations appear to have increased somewhat and now consist mostly of close pack and very close pack (7 to 8 oktas). This apparent increase in ice concentration is probably the result of the overall breakup of the numerous smaller "giant floes" (6.2 to 10 n.mi. across), which are greatly reduced in number in the 22 August data.

As positive identification of the 13 giant floes was possible over the 20-day period, measurements of their motion were conducted. These measurements indicate a gradual clockwise shift in the direction of motion from north to south; in addition, the southernmost floes also moved more slowly. Measurements of four floes between 75°N and 74°N indicate a mean direction toward 176° at a speed of 2.3 to 1.9 n.m. per day. Measurements of six floes between 74°N and 73°N indicate a mean direction toward 206° at a speed of 2.0 to 1.6 n.mi. per day, while measurements of three floes between 73°N and 72°N indicated a mean direction toward 225° at 1.8 to 1.5 n.mi. per day.

Visible surface features in the floes in this area include apparent leads, fractures, cracks, thaw holes, and puddles. Linear features that are brighter than the surrounding areas (in contrast to the dark fractures and cracks) may be ridges or hummocks. These visible surface features suggest that the ice is probably thick first year ice or second year ice. A comparison of the surface features of individual floes over the 20-day period, primarily using the MSS-7 band, shows that noticeable changes do occur. Both puddles (depressions in the ice filled with melt water) and thaw holes (vertical holes in the ice formed when puddles melt through to the underlying sea water) appear as small dark spots on the ice surface, making it difficult to distinguish between the two. However, since many of the smaller dark spots observed on 2 August are not visible on 22 August, it suggests that they are puddles which have refrozen (surface melt water is less dense than sea water, so will freeze at a higher temperature). The larger dark spots which are visible on both dates are undoubtedly thaw holes. Also, as discussed in Section 2.6, the multispectral analysis of the MSS-4 (or MSS-5) and MSS-7 bands provides additional information to distinguish between puddles and thaw holes, since at the shorter wave lengths puddles do not appear as dark as do thaw holes.

Using an enlargement of a portion of one MSS-7 frame on 2 August (image 1010-20293), ice features as small as about 100 m across have been measured. Moreover, it does appear that features (both surface features within floes and isolated ice features) considerably smaller than 100 m across can be seen. Because of their small size, however, it is difficult to measure accurately the exact scale of these features. In the analysis of the enlarged prints, it was observed that the brightness variations indicative of the topography of the ice are not as distinct as in the original 9.5 inch prints. This appears to be due at least in part to the enhancement of the MSS scan lines in the enlarged print.

2.5.4 Greenland Sea (Along East Coast of Greenland from 73° to 80°N)

ERTS imagery for Pass 890, 25 September (identifiers 1064-13342 through 1064-13365), covers the eastern coastal area of Greenland from near 80°N, 01°E southwestward to about 73°N,29°W. Analysis of the MSS-4 and MSS-7 data for this pass reveals wide variations in ice type and concentration. A rather diffuse ice limit extends from just north of 80°N,0°W, southwestward to 78°N,05°W (the picture limit). The observed ice field appears entirely snow covered as surface features such as puddles, thaw holes, ridges, hummocks, and cracks are not visible; also, all adjacent land areas along the Greenland coast are snow covered. Heavy concentrations (close pack to very close pack ice) of varying floe size are observed along the inner region of ice field extending from the coast to approximately 30 n.mi. east, south of 77°30'N. At this latitude the ice floe boundary runs east-west and extends from 100 to 150 n.mi. off the coast as far north as about 80°N (the picture limit). The majority of ice comprising the outer limit of the ice field appears to consist of compacted concentrations of snow covered rotten ice, small floes, ice cakes, and brash ice resulting from the combined effect of surface wind and current flow.

The following describes the major ice and water features observed along the coastal waters, inland bays and fiords (the names of the locations are taken from the ONC B-9 chart):

Germania Land (77°N,19°W)

Shore lead 1/2 to 1 n.mi. wide along the east coast, ice-free up to 15 n.mi. south into Dove Bugt.

Dove Bugt (76° to 77°N, 19° to 20°W)

Brash ice throughout central portion, numerous medium and small floes or icebergs within brash ice in southern region.

Godfred Hansens Island (76°30'N, 20° to 21°W)

Islands surrounded by fast ice.

Bessels Fjord (76°N,20° to 22°W)

Ice-free.

Shannon Island (75° to 75°30'N, 17°20' to 19°W)

Fast ice located in Sengstackes and Nordenskiolds Bugts, large area of flooded fast ice (possibly refrozen) at river mouth in northwest Nordenskiolds Bugt, mostly ice-free 5 to 8 n.mi. off south and west coasts.

Ardencaple Fjord, Bredefjord, Smallefjord, and Grandieans Fjord (75° to 75°40'N, 20° to 22°30'W)

Ice-free.

Young Sund, Tyrolerfjord, and Rudis Bugt (74°20'N, 20°10' to 22°W)

Ice-free.

Copelands Fjord, Godthabs Golf (74°08'N, 22°W) (south and southwest of Clavering Island)

Big, medium and small floes and brash ice (possibly some icebergs and bergy bits).

Moskusokse Fjord (73°40'N, 22°10' to 24°W)

Ice-free.

Kejser Franz Joseph Fjord (73°30'N, 22°10' to 24°W)

Three vast floes observed and a well-defined concentration boundary of compacting of medium and small floes, ice cakes, and brash ice (icebergs and bergy bits may exist) south of Gauss Peninsula. Ice east of Kap Ovibos, west of Ymers Island and in Nordfjord comprised of a few big, medium and small floes within heavy concentration of brash ice. (Icebergs and bergy bits may exist.)

Antarctics Sund, Sofia Sund, Northern Kong Oscar Fjord (73°N, 22°30' to 26°W)

Compacting of small floes, ice cakes, icebergs and bergy bits, and brash ice into narrow belt (approximately 1/2 n.mi. across) along southern coast of Ymers Island in Antarctics Sund; Sofia Sund mostly ice-free. Compacting of apparent small floes, ice cakes, icebergs, bergy bits and brash ice in northern Kong Oscar Fjord east of Suess Land. Kong Oscar Fjord east and south of Ella Island is ice-free.

Isfjord, Western Kejser Franz Joseph Fjord, Kempes Fjord (72°40' to 73°30'N and 22° to 27°45'W) (also 3 smaller fjords west and south)

Ice-free.

Enlargements of portions of some frames (identifiers 1064-13354-13360, and 13363, MSS-4 and MSS-7) provided closer looks of several interesting features. Frame 1064-13354 clearly shows the concentration of snow covered ice floes near the coast and the compacted concentrations of snow covered rotten and brash ice to the east. A giant ice floe (15 n.mi. across) is located at 77°15'N and 16°W. Along the southeast edge of this giant floe is a large area of open water up to 10 n.mi. across. This clearing out of ice is apparently the result of the combined effect of surface wind and current flow.

Enlargements of Frame 1064-13360 shows fast ice present along the north coast of Shannon Island located just north of 75°N and 17°20'W to near 19°W. A darker pattern (in the MSS-7 data) near 75°15'N, 18°10'W in Nordenskiolds Bugt is believed to be the result of flooded fast ice, since a major river with numerous small tributaries empties into the bay at this location. This pattern in the MSS-7 data is not as black as open water, and is light-gray in the MSS-4 band, suggesting that the melt water may have become refrozen.

Several cracks in the fast ice west of Sengstackes Bugt near 75°25'N and 18°30'W are observed in the MSS-7 band.

The enlargements of Frame 1064-13363 show mostly brash ice and a few big, medium and small floes in Nordfjord just west of 24°W. Ice in Kejser Franz Joseph Fjord is comprised of three vast floes and compacting small floes (concentratin boundaries well defined), ice cakes, and brash ice (icebergs and bergy bits may also exist). Two of the vast floes are difficult to distinguish within the areas of compacting, lesser sized floes in the MSS-4 band, because of similar reflectances. In the MSS-7 band, however, they appear distinctly brighter and can be more readily identified. The lesser concentrations of brash ice observed in Nordfjord in the MSS-4 band, are not visible in the MSS-7 band. The differences in the appearances of various ice types in the MSS-4 and MSS-7 bands are discussed further in Section 2.6.

2.5.5 Greenland Sea (Along East Coast of Greenland from 69°N to 74°N)

The imagery from Pass 1057 on 7 October (identifiers 1076-13023 through 1076-13035, MSS-4 and MSS-7) extends from approximately 75°N,16°W to near 69°N,27°W. The overall ice field north of 72°N extends well off the coast (approximately 100 n.mi.) to a diffuse edge of compacted ice belts and eddies (in the area between 16° and 17°W), which appears to be comprised of rotten and brash ice. The observed compacting of the ice into narrow belts and eddies apparently results from the combined effect of surface winds and current flow. South of 72°N the ice field narrows considerably and extends only 40 to 50 n.mi. off the coast.

Enlargements of selected areas of Frames 1076-13023, 1076-13032 and 1076-13035 (MSS-4 and MSS-7) show distinct ice features that are not readily detectable in the original 9.5 inch positive prints. In this case, the original prints, which presumably were processed through standard photographic procedures applied to all images and directed toward enhancement of land features, are too dark to depict much of the sea ice. The experimentation in producing the enlarged prints shows, however, that special processing of the 70 mm negatives to obtain desired brightness and contrast allows ice features to be brought out, although the snow-covered land areas are saturated.

In the enlargement of the area near 73°30' - 74°15'N, 17°-20°W, a boundary is visible between what appears to be deteriorating, consolidated pack ice and areas of rotten and brash ice. The MSS-7 enlargement shows a considerable amount of melt water on the consolidated pack ice between 73°30'N and 74°N, and 19° to 20°W. Flooded ice appears in three small areas, while the remainder of the surface is comprised of numerous puddles or thaw holes. Identification of puddles or thaw holes is difficult to determine in the MSS-7 band, as both appear as dark spots on the ice surface. Examination of the MSS-4 band, however, reveals gray scale differences. In this band, the puddles appear lighter gray, while the thaw holes remain dark. Heavier concentrations of thaw holes exist in the three small regions of apparent flooded ice. These surface melt features suggest that the consolidated pack ice is likely first year ice. To the east of the consolidated pack ice, individual ice floes of various sizes within the areas of rotten and brash ice are readily identified due to their much brighter, and more solid, appearance. The smoother appearance of these ice surfaces suggests second year or multiyear ice.

In the enlargement of the area of Hall Bredning (bay) at the north end of Scoresby Sund, areas of rotten or brash ice and possible icebergs not visible in the original 9.5 inch positive prints can be detected. For example, in the original MSS-4 print, several areas of compacted brash ice appear in a dark gray tone, while large floes or icebergs are barely visible; in the corresponding MSS-7 band, no ice is visible. The MSS-4 enlargement, however, shows distinct northern and southern limits of rotten or brash ice. The northern limit is located just north of 71°N while the southern limit extends from 70°45'N near the west coast of Jameson Land to about 70°40'N near 25°20'W. Also, the actual limits of the areas of compacted brash ice are clearly visible as well as additional areas of compacting with lesser concentrations. In addition, the major floes or bergs appear much brighter and are at a scale that allows measurement of their sizes. Smaller ice features that may be ice cakes and bergy bits are also visible. In the MSS-7 enlargement of this area, only the major concentrations of rotten or brash ice and the larger icebergs are visible.

In another enlargement, what appears to be bands of ice southeast of Kap Brewster in the original print (MSS-4), is seen to be actually the denser portions of a cirrus cloud band. A crescent-shaped ice belt oriented east-west about three miles off the Kap Brewster coast, north of 70°N, can also be seen. The western end of this belt measures approximately 700 ft across while the eastern end narrows to about 300 ft. This ice belt is not visible in the original MSS-4 print. The northern end of another ice belt southeast of Manby Peninsula appears somewhat broader in extent in the enlargement than in the original print; this belt measures about 1000 ft across. In addition, features associated with a vast floe just east of this ice belt, which are not as easily detected in the original print, include a concentration of brash ice along the southern edge and a tongue of ice cakes or brash ice extending off the eastern edge. In the MSS-7 enlargement, puddles and thaw holes around the outer limits of the vast floe are detectable; the vast floe and ice belts are not visible in the original MSS-7 positive print.

In the ERTS data covering the eastern part of Kong Christian Den IX Land, features associated with the numerous glaciers located in this region can be detected. Medial and lateral moraines are observed in the glacier (unnamed) that empties into Barkley Bugt. The two medial moraines measure about 600 ft across and are about 1 n.mi. apart. A glacial tongue at the end of this glacier in Barkley Bugt also appears in the MSS-7 band as a distinct feature. In the corresponding MSS-4 band, the tongue cannot be distinguished from the surrounding sea ice. However, many features that are probably icebergs, bergy bits, or ice cakes, can be seen in each of the coastal bays in the MSS-4 data.

2.6 Multispectral Characteristics of Sea Ice

The initial investigation of the multispectral characteristics of sea ice and other features has concentrated on a comparison between the MSS-4 (0.5 to 0.6 μm) and MSS-7 (0.8 to 1.1 μm) bands. The results of the initial analyses of these spectral bands in passes crossing the Beaufort Sea (1053-22503), Banks Island (1043-20120), the Thule, Greenland area (1062-16504) and the east coast of Greenland (1064-13354), in addition to the passes described in the previous sections, are summarized below:

1. Overall contrast is greater in the MSS-7 band. Open water areas and mountain shadows appear blacker than in the MSS-4 band.

2. Some areas of sea ice that appear uniformly bright at MSS-4 are very dark at MSS-7; these are believed to be areas of melt-water on top of the ice surface. Other features that appear dark in both bands are believed to be cracks or thaw holes through the ice. Thus, through use of both spectral bands, puddles can be distinguished from cracks and thaw holes.

3. Areas of apparent brash ice appear darker than areas of thicker ice at MSS-4, but can still be easily detected; these areas are difficult to distinguish from open water at MSS-7. However, ice floes that are difficult to distinguish from surrounding ice at MSS-4 because of similar reflectances, appear distinctly brighter than the surrounding ice at MSS-7.

4. In areas of nearly solid ice cover, greater detail is evident at MSS-7, This is primarily because tonal differences between ice floes, brash ice, and cracks and openings are greater at MSS-7 than at MSS-4. Also, tonal variations within some ice floes are evident at MSS-7; these variations may be associated with hummocks, ridges, or refrozen leads.

5. Broken cloud fields over ice are more easily distinguishable at MSS-7 because of more distinct shadows, both on the ice surface and within the cloud field itself. However, the most reliable method to distinguish between clouds and ice is to use both the MSS-4 and MSS-7; at MSS-7 cracks in the ice and cloud shadows have similar reflectances, whereas at MSS-4 the cracks appear significantly darker than do the cloud shadows.

6. Glaciers on the coasts of Greenland generally have a uniform reflectance throughout their extents at the MSS-4 spectral band. The lower extents of several of these glaciers, however, appear much darker at the MSS-7 band. This difference is likely due to melt water covering the lower portion of the glacier as opposed to snow covering the higher elevation part.

3. NEW TECHNOLOGY

No new technology has been developed during the first six-month period of the subject contract.

4. PROGRAM FOR NEXT REPORTING PERIOD

During the next reporting period further analysis of the present data sample will be performed. It is doubtful that much new data will be received during the next period because ERTS will not collect data over the Arctic until sufficient light returns to those latitudes. However, much usable data on hand have not yet been analyzed. Also, it is anticipated that the sample of color composite data requested some time ago through the retrospective data request procedure will be received in the near future.

Correlative aerial survey ice charts for specified areas and dates have been requested from the Navy Ice Forecast Office. When these ice charts are received, the ice types that appear to be identifiable in the ERTS data can be verified, as well as the ice concentrations. It is realized, of course, that even the aerial survey ice charts do not provide information on the scale of detail that can be detected at the ERTS resolution. The ice charts are the best source of ground truth, however, and will be particularly useful if the date of the flight is within a few days of the date of ERTS passage.

5. CONCLUSIONS

Sea ice is detectable in all of the ERTS MSS spectral bands because of its high reflectance. The photographic processing of prints from the original 70 mm negatives can be important for ice detection, however, since exposures selected to retain detail in land areas may result in the loss of significant ice features. Overall, the MSS-4 (0.5 to 0.6 μm) and MSS-5 (0.6 to 0.7 μm) bands appear to be better for mapping ice boundaries, whereas the MSS-7 (0.8 to 1.1 μm) band provides valuable information on ice type and ice surface features.

Sea ice can be distinguished from clouds because the brightness of ice fields and ice floes is often more uniform than that of clouds; ice floes and features such as leads and fractures within ice fields can at times be detected through thin clouds; cloud shadows can often be detected on the underlying ice surface; edges of most ice features are more distinct than edges of clouds; ice cover fits coastlines and islands, permitting land features to be recognized; the spatial frequencies of ice features are not characteristic of cloud patterns; and when repetitive coverage is available some ice features can be identified over 24-hour or even over larger intervals.

Considerable information on ice type can be derived from the ERTS data. Ice types that appear to be identifiable include: ice floes of various categories, pack ice of various concentrations, ice belts, brash ice, rotten ice, fast ice, leads, fractures, cracks, puddles, and thaw holes. Although larger icebergs can be seen, it is difficult to distinguish them from ice floes. Ice features as small as the "small floe" (20 to 100 m across) can be detected, and the sizes of features somewhat smaller than 100 m across can be measured from enlarged ERTS prints. Ice concentrations can be mapped, and the resulting concentrations are in good agreement with the limited amount of correlative data available to date. Ice features can be identified over 24-hour periods enabling their movements to be measured; some large floes can even be recognized over intervals of as long as 20 days, enabling mean ice movements over longer periods to be determined.

The multispectral analysis of the ERTS MSS-4 and MSS-7 bands provides much information on ice type and ice surface features that cannot be derived from a single spectral band. For example, thaw holes can often be distinguished from puddles because of their different appearances in the two bands. These surface features can be indicative of ice age. Furthermore, snow lines on glaciers can be reliably mapped through the joint use of the MSS-4 and MSS-7 data.

6. RECOMMENDATIONS

Specific recommendations will await further data analyses to be conducted during the next reporting period.